Author Response and Manuscript Revision

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September 2022

Dear Dr. Burrows,

Please find our response to the second round of Reviewers comments and our revised manuscript 'Southern Ocean cloud and shortwave radiation biases in a nudged climate model simulation: does the model ever get it right?'.

We have addressed all of Reviewer 2's comments, and have tried to more carefully explain our reasoning with respect to Reviewer 1's comments. We appreciated Reviewer 1's concerns but are confident that what we have done is not incorrect. We hope that our further explanation and changes to the text satisfies both you and the Reviewer.

Kind regards,

Dr. Sonya Fiddes

Response to Reviewer 1

We thank this reviewer for taking the time to consider our revisions. We have addressed the comments below and hope that our answers address their concerns. We believe that our method is robust, though we acknowledge that a different choice may lead to different results. Please see our detailed comments below.

There remains one serious issue, which is that the authors appear to be comparing clivi and clwvi-clivi (see line 195) to MODIS in-cloud IWP and LWP. It is stated: "For this reason, as stated above, the actual simulated (i.e. direct model output) IWP and LWP are used for this analysis instead of the COSP product. "

We would like to reassure the reviewer that we are not comparing two different products in our analysis. We have carefully reviewed each product used in this work to ensure we are comparing the correct version (in-cloud versus grid box mean) and units. As part of this process, we have consulted with both UM and MODIS experts to seek clarification on aspects of the data sets including units and confirmation of grid-box vs in-cloud mean output.

Firstly, we are comparing clivi and clwvi (not clwvi-clivi as suggested) separately. The sentence stated above refers to our choice to use the raw model output as opposed to the model output that has been run through the COSP simulator. We will touch on this more below and have slightly modified the aforementioned sentence:

Line 196: 'For this reason, as stated above, the actual simulated (i.e. raw model output) IWP and LWP are used for this analysis instead of the COSP derived product.'

Both the COSP and raw modelled LWP and IWP are output as grid-box mean from the ACCESS model. The MODIS data, as the reviewer states, is an in-cloud mean estimate. So in order to satisfactorily compare the two, a conversion is needed, where:

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grid box mean = in-cloud mean x cloud fraction
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We have compared both methods. Converting the MODIS product to grid box mean as well as the model products to in-cloud mean (see here) reveals that there is no completely satisfactory solution. Comparing in-cloud values lead to very large model biases, where as the grid-box mean values were better represented for the LWP, but not the IWP. This is likely due to their weighting by cloud fraction. We have now made this clear in the text.

Line 162: 'Furthermore, care has been taken to ensure that we are comparing only grid-box mean values of the LWP and IWP. Model outputs (both COSP and raw) are provided directly as grid-box mean, while the MODIS products are provided as in-cloud mean values. We have performed the appropriate conversions where grid-box mean is equal to the in-cloud mean multiplied by cloud fraction. After comparison of both grid-box mean and in-cloud mean values, we have chosen to use the grid-box mean values.'

Similarly, as mentioned above, we have compared the COSP model output as well as the raw model output. The magnitudes of the raw model output were marginally better when compared to MODIS than that of the COSP model output, leading to our decision to use the raw output in this instance.

If you are using these outputs there isn't really an observational IWP for grid-box mean, but you can use microwave radiometer output.

We appreciate that the converted IWP grid box mean may not be the best product to use, however we do not wish to mix and match products. The advantage of the MODIS products is that we can use the retrievals for a number of cloud properties to directly compare with our model in a consistent manner. Although other products and measurements could be used to evaluate each cloud property separately, that would need to be a different study that would carefully deal with the caveats of the inconsistencies in measuring or retrieving the different cloud products to compare to a model.

Swapping in-cloud and area-mean LWP between GCM output and observations would seem to explain Fig1 a4 and b4 where there is a big latitudinal bias that seems like it follows the distribution of cloud

fraction since in-cloud LWP*CF   area-mean LWP.

Yes, the reviewer is right that there is some dependence of the LWP (and IWP) on the cloud fractions, as we have used the grid-box means. We have made further note of this in the text:

Line 166: 'This choice does effect some of the results of this study, as would choosing to use the in-cloud values instead. However, we believe this choice is robust for two reasons: firstly, grid-box means are the native model output and this is a model evaluation study and secondly, the grid-box means showed a better model performance than the in-cloud mean values, likely due to the weighting of the cloud fraction.'

It should also be noted that in the caption for figure 1 the units of a path are g/m2 not g/m3.

We have fixed the units in this caption

Because it is hard to say what swapping out the ice and liquid path variables will do I mark this major revisions.

We appreciated the Reviewer's concern with this aspect of our methodology and we hope that we have been able to convince them that what we have done is robust, within the limits of the data available. We have included further discussion about these choices in our conclusion to ensure that we are acknowledging the caveats raised by this Reviewer.

Line 600: 'Similarly, having to convert between in-cloud and grid-box mean water paths has added another layer of uncertainty to this work. We chose to use the grid-box mean values, but the use of in-cloud values would have changed the our results and their interpretation. Whilst the COSP framework and specifically derived MODIS product go a long way to helping model evaluation, more needs to be done to ensure that modellers can use an observational products with confidence and minimal transformation. '

Response to Reviewer 2

We have addressed all of the minor comments from Reviewer 2 below.

Sentence starting on line 180 has a slightly confusing clausal structure maybe "The MODIS products provide the best coverage over the time period examine, hence we choose to focus on MODIS data"

We have revised the sentence as follows:

Line 188: 'The MODIS products provided the best coverage for the time period of interest to this study. For this reason, no other satellite products are considered in this work.'

I think the sentence starting on line 183 needs to be rewritten for clarity

We have revised the sentence as follows (and also removed the previous one).

Line 191: 'Using COSP output allows the appropriate comparison of model to satellite products. This method applies the assumptions and limitations of the satellite algorithms to the model output, limiting the possibility that biases are due to differences in processing.'

The sentence starting on line 215 should be simplified. I think something like "This choice will allow us to assess if any changes applied to the model focussed on improving Southern Ocean clouds have unintended effects outside this region."

We have amended this sentence following the reviewers recommendation.

Line 223: 'This choice will allow us to assess if any changes applied to the model focused on improving Southern Ocean clouds have unintended effects outside this region.'

Line 227 change represent to "are set so that" and then change rest of sentence to fit

We have revised the sentence to:

Line 235: 'The boundaries of our analysis, shown by the dashed lines, represent three regions of interest: the mid-latitudes defined as 30-43°S, the sub-polar region defined as 43-58°S, and the polar region defined as 58-69°S of the SO.'

I think the sentence starting on line 263 needs to be rewritten for clarity

We have revised the sentence to:

Line 271: 'In the mid-latitude region however, both the cloud fraction biases (liquid and ice) are weakly negative. This indicates too few clouds overall in this region, which can explain the positive $SWCRE_{TOA}$ bias.'

I think the sentence starting on line 293 needs to be rewritten for clarity

We have revised the sentence to:

Line 301: 'These results show that in the polar region, the biases in cloud fraction and water paths can satisfactorily explain the $SWCRE_{TOA}$ bias. For the other two regions however, the influence of the cloud biases is not as clear cut.'

I don't think the sentence starting on line 304 makes sense. Maybe change the start to "The k-means clustering technique was applied to MODIS daily joint histograms...."

We have amended the sentence to:

Line 312: 'The k-means clustering technique was applied to five years of MODIS daily-mean joint histograms over the entire globe. The 12 resulting cluster centres are shown in Figure 2.'

I think the sentence starting on line 390 needs to be rewritten for clarity as it has a complex clausal structure.

We have split this sentence into two as follows:

Line 388: 'The synoptic meteorology is considered to be the same in the model and the observed conditions, due to the nudging of the model. We therefore expect that the model microphysics, if accurate, would generate the same cloud types that the large-scale dynamics prescribes.'

I think the wrong citation command is used for the bender et al. 2017 reference on line 604

Fixed